LA-UR-81-1074
CONF-810429--10

MASTER

TITLE: AN ULTRAVIOLET-SPECTROGRAPH LENS

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SUBMITTED TO: Los Alamos Conference on Optics, April 7-10, 1981, Santa Fe, New Mexico

University of California

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CONTRACT W-7405-ENG. 36

An Ultraviolet Spectrograph Lens

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Abstract

A 700-mm *f*/4.7 spectrograph camera lens was designed for imaging spectral lines in the 200- to 400-nm region on a 120-mm flat image field. Lens elements of fused silica and crystal calcium fluoride give such good achromatization that raytracing calculations predict a resolution limit of 30 lines/mm without refocusing in the 238- to 365-nm region. Light scattering at the polished calcium-fluoride surfaces is avoided by sandwiching the fluoride elements between fused silica and cementing with silicone fluid. The constructed lens makes good spectrograms.

Introduction

The ultraviolet spectrograph lens to be described was designed to replace the visible-light camera lens in the Los Alamos MOD-40 Sweeping Image Spectrograph,[1] which sweeps very short spectral lines along the film to get data for the study of rapidly changing events.[2] The problem was to design a lens that would focus light in the 200- to 400-nm region with a resolution of about 15 lines/mm and good contrast throughout the 10-degree image field needed for recording on a 102 by 127 mm photographic plate.

For wide ranging surveys, the correction of longitudinal chromatism should be so complete that, without refocusing, the desired resolution would be obtained for all wavelengths at all parts of the image field. However, complete adherence to this difficult performance specification is not essential because recording at the optimum focus is usual when studying a particular spectral line. Fortunately, the lens-design calculations indicated that most of the desired performance would be obtained without refocusing. The first test films show sharp recordings of a few mercury lines, thus leading to the expectation that the desired performance will be achieved. Because quantitative evaluations are not yet available, we can only say that performance of the new lens seems to exceed the 10-line/mm photographic resolution that was obtained with the visible-light lens, which was a quadruplet made with ordinary optical glasses for imaging in the 400- to 700-nm region.

Discussion

There were several special problems to be overcome before a successful general-purpose ultraviolet lens could be constructed. The first problem was the discovery of optical glasses with good light transmission when a 200-mm thickness is used in the 200- to 400-nm spectral region. The large thickness is needed for construction of the large camera lens, an objective lens, and an explosion-proof window. The glasses must have dispersion characteristics suitable for use as crown and flint glasses. Fortunately, these glasses had already been discovered by earlier workers. Large artificially-grown single crystals of optical-grade calcium fluoride are available for use as the crown elements. Ultraviolet-grade optical fused silica is available for use as flint elements and windows.

The second problem is the poor polish taken by the soft crystalline calcium fluoride. The residual roughness of the best available polished surface scatters light that degrades the image contrast an intolerable amount. To overcome this difficulty, the fluoride elements are cemented between fused silica elements, a construction complication and a design disadvantage. To eliminate the light scattering by surface roughness, the cementing agent must have a refractive index close to that of calcium fluoride, transmit the light efficiently, and remain pliable during thermal expansion changes. The lengthy search for a suitable cementing agent turned up silicone fluid (20,000 centistoke viscosity), which has very good transmission to 200 nm when used in thin films, is quite inert, has a very low evaporation rate at room temperature, and freezes at a low temperature.

The third problem is the procurement of an antireflection coating that has low reflection and high transmission characteristics in the 200- to 400-nm region. To obtain good durability and wide-band antireflection characteristics, a multilayer coating is probably needed. Unfortunately, that coating is not generally available at the present state-of-the-art. Fortunately, the uncoated lens makes satisfactory images.

Discovering the New Lens Design

The Los Alamos lens design code[3] was used to find the 700-mm *f*/4.7 spectrograph lens design. The Los Alamos designing program minimizes the errors in the sizes and the positions of the image spots, which are generated by multiple raytracing. This designing procedure leads directly toward diffraction-limited performance and the closest possible approach to the diffraction modulation transfer function.[4]

Because a quadruplet type of lens construction (with crown, flint, flint, and crown glass elements) gave satisfactory visible-light images, it was assumed that a similar construction could be achromatized for the ultraviolet region when fused silica and calcium fluoride elements were used. The first step in finding the ultraviolet design was to see if a quadruplet with four fused-silica elements would give satisfactory monochromatic image quality throughout a 10-degree flat image field. A lens of 700-mm focal length working at about f/4.7 relative aperture was required for use in the existing spectrograph. The desired monochromatic design was soon found. Next, the monochromatic design was achromatized by substituting elements of calcium fluoride sandwiched between fused silica for the single fused silica elements of the monochromatic design. Several combinations were tried until the design shown in Figure 1 and Table 1 was found to give satisfactory performance.

The most important lens performance characteristics, calculated by multiple raytracing, are shown in Table 2. The first part of the table shows the image spot sizes for three representative wavelengths at each of four representative image positions. Those numbers suggest that images with good contrast will be obtainable at 15 lines/mm. Diffraction modulation transfer function calculations indicate about 50% modulation at 15 lines/mm and best focus. The rms radius of the rays in the spot is a good measure of the image resolution. Experience has shown that this estimate of resolution agrees well with the visual resolution when measured on the optical bench with bar-chart targets. An 0.01 rms radius predicts that 100 black and white line pairs per unit will be just resolvable. The ultraviolet resolution was not measured because suitable instrumentation was not available. However, raytracing in the visual range gave an estimated resolution that was confirmed on the optical bench.

The second part of Table 2 shows the image distortion and lateral chromatism. Distortion is the deviation of the images from the positions required by rectilinear geometry. Lateral chromatism is the maximum lateral deviation of the image positions at the different wavelengths. If uncontrolled, both deviations usually increase as the image height increases. Both deviations were uncontrolled in this design and therefore are quite large. The distortion deviation varies from +1.0 to -1.2 mm at the field edge. The lateral chromatism is 2.2 mm. Because the lens only makes monochromatic images that are swept a short distance along the plate, those large image errors are not detrimental to the data recorded by the spectrograph. The main achievement of this lens is its ability to make sharp monochromatic ultraviolet images throughout the photographic plate.

Acknowledgements

Our thanks go to R. E. Lapp and B. J. Montoya for their careful attention to details while making and testing this lens. Thanks also go to T. Bieniewski, D. F. Edwards, and R. E. Watt for their ultraviolet transmission measurements that helped to get this lens into successful operation. Work supported by the U. S. Department of Energy.

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Table 1. Prescription for Los Alamos Type 137 Ultraviolet Lens[a]

Material	Surface	Radius	Thickness
	1	182.8	
Silica			20.0
	2	1397.1	
Air			129.851
	3	-294.0	
Silica			7.0
	4	182.8	
Fluoride			20.0
	5	-208.2	
Silica			7.0
	6	162.6	
Air			69.518
	7	-894.0	
Silica			7.0
	8	231.0	
Fluoride			35.0
	9	-132.5	
Silica			7.0
	10	-334.5	
Air			5.0
	11	253.5	
Silica			7.0
	12	148.7	
Fluoride			35.0
	13	-301.2	
Silica			7.0
	14	-486.0	
Air			503.563
	15	PLANO	

[a]Dimensions are in mm. Entrance pupil 100 behind first surface.

Table 2. Performance of Los Alamos Type 137 Ultraviolet Lens[a]

Image height, mm	00	20	40	60
Wavelength, nm	Image spot size, rms radius, mm			
365.0	0.018	0.019	0.024	0.030
280.3	0.014	0.016	0.023	0.031
237.8	0.016	0.019	0.023	0.026
	Distortion, mm			
365.0	0.0	+0.231	+0.530	+0.976
280.3	0.0	-0.108	-0.146	-0.033
237.8	0.0	-0.505	-0.938	-1.218

[a]All evaluations are calculated at 503.563-mm back focus.

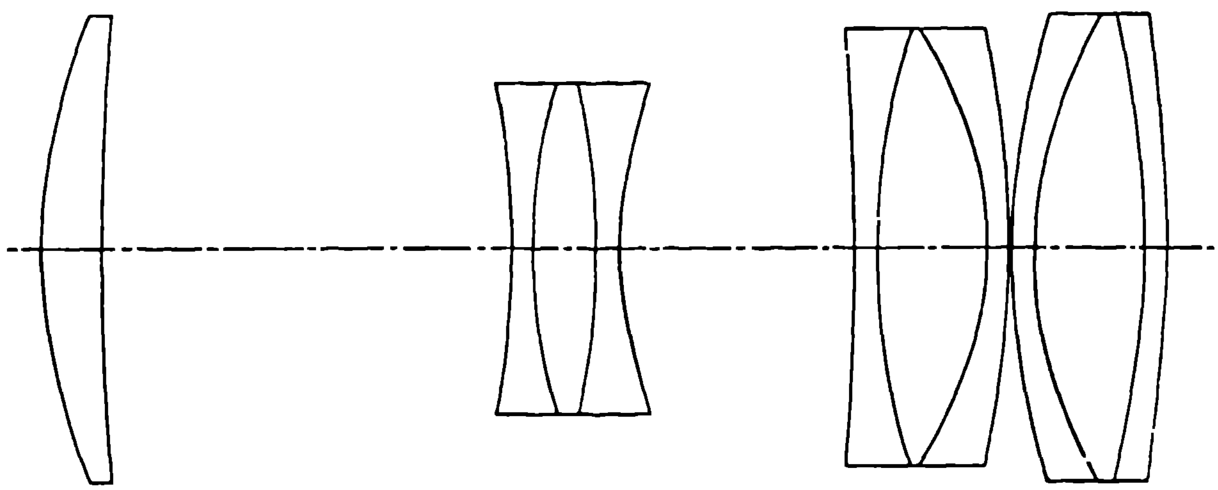

Figure 1. Los Alamos Type 137 Ultraviolet Lens.